creasing the period of safe plant growth from 210 days near the shores to 190 days at distances only 20 to 25 miles inland, a difference of 20 days. Differences in soils are doubtless in part responsible for these variations.

In the mountain districts of the Blue Ridge (see fig. 1) we have a striking example of the protecting influence of a mountain range stretching across the path of the prevailing westerly winds. On the western or windward side of the Blue Ridge, in the lower levels of the Cumberland Valley, the frost period extends into the first week of May and reappears in the fall in the first decade of October, showing a period of safe plant growth of about 160 days. On the eastern or protected side of the Ridge the period is lengthened to 190 days, and even 200 days, the freezing temperatures disappearing about April 15 and reappearing in the third decade of October. In the mountain districts the variations in the length of the season are to some extent due to cold-air drainage during clear and calm nights and can not be altogether attributed to the protecting influence of the mountains against the cold westerly winds.

In the most western county of Maryland we find another factor entering into the length of the period of safe plant growth, namely, that of elevation, as shown by figure 1. The general level of Garrett County is not far from 2,500 feet above sea level, with peaks rising to 3,000 feet. Here we have a very decided shortening of the period, injurious frosts extending into the early days of June and appearing again about the middle of September, showing a period of safe plant growth of but little more than 100 days in the areas exposed to intense nocturnal radiation and to extensive air drainage.

THE PROGRESS AND PRESENT STATE OF RESEARCH ON THE EVAPORATION OF MOISTURE IN THE ATMOSPHERE.

[Communicated to the International Meteorological Congress at Chicago, Ill., August, 1893.]

By Prof. Dr. AUGUST WEILENMANN.

[Dated, Zurich, July, 1893. Revised by the author March 24, 1901.]

[Prof. August Weilenmann died at Zurich, November 10, 1906, at the age of 64. Besides his activities in his chosen field of astronomy, he ranked among the leading Swiss meteorologists of his time. Under the general direction of the astronomer Wolf, he was put in charge of the observational material collected by the meteorological réseau of Switzerland when that work was begun in 1863-64 under the care of the then newly established astronomical observatory of the Federal Polytechnikum. He continued in charge of this work, contributing many papers to the "Schweizerische meteorologische Beobachtungen," until 1872, when he was succeeded by Billwiller.

In 1873 Weilenmann withdrew from the astronomical observatory and devoted himself with brilliant success to teaching mathematics, physics, and meteorology in the higher cantonal schools. For 30 years he lectured on meteorology at the University and the Polytecnikum in Zurich. His extremely clear and inspiring lectures made all these subjects interesting and useful to a very wide circle of hearers.

The present paper, as noted above, was revised by its author and prepared for publication in 1901; publication has been delayed for the reasons stated in the REVIEW for February, 1914, p. 93.—C. A., jr.]

The evaporation of moisture was for a long time totally neglected in meteorology as a matter of observation, although it is one of the most important of the elements whose concurrence constitutes the weather. Kämtz in his Meteorology in 1831 gives only three pages to this phenomenon and mentions only the observations of Dalton in England and of some others made at various places in France and Holland. Schübler in his Meteorology of 1831 gives his own results at Tübingen. Schmid in his great treatise of 1860 knows no other observations than those already mentioned, by Kämtz and Schübler, and on page 600 he says: "The total result of these observations on evaporation simply leads to the conclusion that it is absolutely impossible to determine even approximately the quantity of moisture that passes from the surface of the earth into the atmosphere during a given time and at a given place." Although this conclusion may be true to a certain degree, and although the observations made under diverse conditions may not be absolutely comparable and may differ in total amount from the quantities that evaporate from the ocean or the open surface of the land, still the researches and experiments on this subject are of great importance and furnish a useful factor wherewith to characterize the climate of a given place. Moreover, the observations organized by Wild in Russia and by Hann in Austria-Hungary show that the results obtained with similar instruments similarly exposed are comparable. Therefore, in spite of the discouraging words of Schmid, the observations of the evaporation of moisture have not been abandoned, but rather have been greatly increased since 1860. The space conceded to this present report does not allow me to communicate all [1] that has been accomplished within the past 50 years (1843–1892), but it may be sufficient to give the most important results. I shall divide this paper into two portions: Theory and Instruments and observations.

THEORY.

The well-known physicist Dalton was among the first to endeavor to state the connection between evaporation and the elements on which it depends. He gives the following formula for the rate of evaporation:

$$\frac{dv}{dt}=\frac{A\ (S-s)}{b}$$

In this formula A is a constant, S the maximum aqueous vapor pressure for the temperature of the water surface, s the actual vapor pressure present in the air, b the atmospheric pressure.

This expression does not take into account the very appreciable influence of the motion of the air or the wind.

A. Weilenmann, of Zurich, has treated (1) the same problem. The principle on which this theory is based is mathematically the same as that of the wave motion of the molecules of fluids, assuming a constant duration for the vibrations in the same fluid. It also takes into consideration the atmospheric pressure, b, which diminishes the amplitude of the vibrations, and the motion of the air which favors the renewal of that which has become saturated with vapor. It further assumes that the air moving close to the surface of the water becomes completely saturated. By this theory we find the following expression for the depth, h, of the layer of water evaporated in the time z.

$$1)\quad h=\frac{\beta}{b}\int_0^z m_1dz+\beta_1\int_0^z m_1wdz$$

where β and β_1 are constants; b the atmospheric pressure; $m_1=G_1-g_1$, where G_1 is the weight of the vapor in a cubic meter of saturated air at the temperature, t_1, of the surface layer of evaporating water, and g_1 the weight of the vapor actually existing in a cubic meter of air before con-

[1] See "An annotated bibliography of evaporation," MONTHLY WEATHER REVIEW, June, 1908, to June, 1909. Also reprinted.—EDITOR.

tact with the layer of water; w the velocity of the wind. If a psychrometer is observed in the vicinity of the evaporometer, we can express m_1 in terms of the temperatures, t and t_1, of the dry- and wet-bulb thermometers, and we thus find

$$2)\quad h=\gamma\int_0^z\frac{t-t_1}{T}dz+\gamma_1 b\int_0^z\frac{t-t_1}{T}wdz$$

where $\gamma=\frac{\beta}{b}$ and $\gamma_1=\frac{\beta_1}{b}$ are constants and $T=273°+t$, is the absolute temperature in centigrade degrees.

If T_m is the mean value of T we shall, with sufficient approximation, have

$$3)\quad h=\frac{\gamma}{T_m}\int_0^z(t-t_1)dz+\frac{\gamma_1 b}{T_m}\int_0^z(t-t_1)wdz$$

and the rate of evaporation becomes:

$$4)\quad u=\frac{dh}{dz}=\frac{\gamma}{T_m}(t-t_1)+\frac{\gamma_1 b}{T_m}(t-t_1)w.$$

For any given station these expressions become:

$$5)\quad h=\varepsilon\int_0^z(t-t_1)dz+\varepsilon_1\int_0^z(t-t_1)wdz$$

$$6)\quad u=\varepsilon(t-t_1)+\varepsilon_1(t-t_1)w$$

where ε and ε_1 are constants for that station.

These equations, assuming the velocity of wind to be constant, express the law first enunciated by Tate (**2**) that the velocity of evaporation is proportional to the psychrometric difference, or the depression of the wet-bulb below the dry-bulb.

But as most publications of climatological data give only the temperature of the air and the aqueous vapor pressure, it is necessary to recalculate the difference $(t-t_1)$ by the ordinary psychrometric formula:

$$7)\quad S_1-s=kb(t-t_1)$$

where S_1 is the tension of saturated vapor at the temperature t_1 of the wet-bulb; s the actual tension of vapor present in the air at the temperature t of the dry-bulb; $k=0.00066$, when the pressures are expressed in millimeters of mercury and the temperatures in degrees centigrade. For any given place b and k may be combined as being approximately constant. Let

$$8)\quad S_1=S-\alpha(t-t_1)$$

where S indicates the tension of saturated vapor at the temperature t; then will α vary with the temperature in a definite manner.

Putting $$\eta=\frac{273}{(\alpha+kb)(273+t)}$$

and the deficit of saturation, d, equals S_1-s we have:

$$9)\quad u=\theta\eta d+\theta_1\eta wd$$

$$10)\quad h=\theta\int_0^z\eta ddz+\theta_1\int_0^z\eta wddz$$

θ and θ_1 are constant for the same station, but $\theta_1=\theta_2 b$ depends upon the atmospheric pressure b.

Instead of integration we must here use approximately a summation for each day individually. It is, moreover, sufficient to operate with the hourly means for each month.

This calculation as effected for several stations, gives results that accord satisfactorily with the observations. If D designates the monthly mean of ηd, WD the monthly mean of ηwd, and z the number of days, then the total monthly evaporation is:

$$h=\mu[zD+\gamma z\,WD].\quad \text{[See footnote }^2\text{.]}$$

The constants in this equation have been determined for several stations as follows:

Vienna	$\mu=0.673$; $\gamma=0$
Pola	$\mu=0.726$; $\gamma=0$
St. Petersburg	$\mu=0.675$; $\gamma=0$
Paris (Piche evaporometer)	$\mu=0.769$; $\gamma=0.058$

In the proceedings of the Academy of Vienna, Stefan (**3**) gives a theory of evaporation in continuation of the experiments published by him in 1874. The experiments were made on fluids more volatile than water and which did not absorb water from the air; the fluids were placed in tubes of small diameter whose upper ends were freely exposed. The following laws were deduced (**4**):

1. The rate of evaporation is proportional to the logarithm of a fraction whose numerator is the atmospheric pressure and whose denominator is the difference between the atmospheric pressure and the saturation vapor pressure.
2. The rate of evaporation of a liquid in a tube is inversely proportional to the distance from the open end of the tube down to the level of the liquid.
3. The rate of evaporation, u, is independent of the diameter of the tube.

These three laws are expressed by the formula:

$$11)\quad u=\frac{k}{h}\log\frac{p}{p-p_1}$$

where k is the constant of diffusion; p, the atmospheric pressure; p_1, the saturation vapor pressure; h, the distance of the level of the liquid below the open end of the tube.

Stefan then shows that the equation for the rate of evaporation leads to a form of equation that shows the analogy with conduction of heat and electrostatics. At the surface of the liquid the air is saturated and the tension of the vapor diminishes with the distance from this surface. He also finds for the quantity of vapor, v, passing in a unit of time through any level surface in the tube above the liquid, at which the vapor pressure is p_0, the following expression:

$$12)\quad v=-k\frac{dU}{dn}$$

where

$$U=\log\frac{p-p_0}{p-p_1}$$

and where dn is an element of the normal to the level surface under consideration. For the steady condition, where the quantity which passes through any level sur-

[2] [NOTE.—In this equation the author has substituted $\mu=\theta$ and $\gamma=\frac{\theta_1}{\theta}$ as now representing approximate generalizing factors that must be determined from the observations and are not to be confused with the γ of equation (2).—C. A.]

face is just equal to the quantity evaporated, the condition to be fulfilled is

$$13)\quad \frac{d^2U}{dx^2}+\frac{d^2U}{dy^2}+\frac{d^2U}{dz^2}=0,$$

where x, y, z are the coordinates of the point in space at which the steady condition obtains.

Stefan subsequently undertook the solution of the following problem: In an infinite plane, which neither gives out nor absorbs vapor, nor allows it to pass through, there is a hole filled with liquid, so that its level surface coincides with that of the plane; the liquid evaporates into the infinite atmosphere over the plane; it is required to calculate the quantity of vapor, V, passing from the liquid into the air when the evaporation has reached the stationary condition.

For a circular surface, or tube, he finds the quantity of evaporation:

$$14)\quad V=4ak\log\frac{p-p_0}{p-p_1}$$

$$V=4ak \text{ etc.},$$

and for small values of p_1 and p_0 this becomes:

$$15)\quad V=4ak\,\frac{p_1-p_0}{p}$$

where a is the radius of the circle and the other quantities have significations as already defined.

The quantity of evaporation, therefore, is not proportional to the surface of the evaporating liquid but to the circumference of the basin.

This result is also applicable to an elliptical circumference if the eccentricity is not more than 0.96.

The quantity of evaporation from a surface whose radius r is less than a is:

$$16)\quad V_1=V\left(1-\sqrt{1-\frac{r^2}{a^2}}\right)$$

If the level of the evaporating surface is at a distance, h, below the edge of the vessel, then the quantity of evaporation diminishes in the ratio:

$$\frac{r-h}{r}.$$

This investigation is certainly very interesting. Formula (15) has the same form as the first term of equation (1) of Weilenmann, or of the Dalton formula, which represents the rate of evaporation without considering the influence of the motion of the air, or the wind. But if the quantity evaporated is proportional to the circumference of the vessel then the depth of evaporated liquid must be in inverse ratio to the radius, and we must reach the conclusion that in a very extended vessel, as, for instance, the ocean, the depth evaporated would be 0.

On December 22, 1861, E. Stelling (**5**) presented to the Academy of Sciences at St. Petersburg, a treatise "On the Evaporation at Pavlovsk." He uses the Dalton-Weilenmann equation in the form:

$$17)\quad v=A\Sigma(S_1-s)+B\Sigma(S_1-s)w,$$

which is obtained by assuming the barometric pressure as constant and substituting in equation (8) of Weilenmann, as above given, the value of $(t-t_1)$ from his equation (7). A and B are constants, v the quantity of water evaporated; S_1 the vapor pressure for saturation at the temperature of the surface of the water, and s the actual vapor pressure of the vapor present in the air. The observations at Pavlovsk were made with an evaporometer floating in a basin so that the two levels of the water, within and without, were at the same heights; he finds sufficient accordance between observation and calculation.

Prof. Cleveland Abbe (**6**) proposes to employ the evaporometer in a shelter, as an integrating hygrometer. He illustrates this by the observations of FitzGerald (**7**) made in 1876–1882 at the Chestnut Hill Reservoir near Boston, where the following formula is given:

$$18)\quad E=0.0166(V-v)(1+\tfrac{1}{2}w)$$

E is the depth of water evaporated hourly, expressed in inches; V the maximum vapor pressure for the temperature of the water, also expressed in inches; v the maximum vapor pressure for the dew-point of the free air before it has had access to the evaporating surface; w the velocity of the wind, expressed in miles per hour, at the evaporating surface itself. From this formula the average dew-point for an hour or any other interval results as follows:

$$19)\quad v=V=\frac{60E}{1+\frac{1}{2}w}$$

Already in 1862 Tate (**2**, v. 23, p. 130) had proposed a certain form of evaporometer answering the purpose of a hygrometer (**8**).

Prof. Thomas Russell (**9**) communicates the lines of equal evaporation for the United States of North America, as calculated from the psychrometric observations made at the stations of the Signal Service. Basing his studies on the above-mentioned treatise of Stelling (**5**) and on observations made in 1888 at 19 stations with the Piche apparatus, which he reduces to observations over an open water surface and for a mean velocity of the wind of 13 kilometers (8 miles) per hour by dividing by the factor 1.33. Russell finds that the quantity evaporated can be expressed in inches by the following:

$$20)\quad V=[1.96\,p'+43.9(p'-p'')]\frac{30}{b}$$

where p' is the vapor pressure for the temperature of the wet-bulb and p'' the vapor pressure for the dew-point, both being expressed in inches.

Dr. W. Ule (**10**) speaks of the evaporating power of a climate, meaning thereby the greater or less ability of the air to desiccate a body. This desiccating power must be proportional to the vapor tension of the air and we have a measure of this climatic element in the variation in weight of a body. The intensity of the desiccating power and the rate of desiccation are to be distinguished from each other. Ule thinks that the weighing apparatus of Wild is well adapted to determine the rate of desiccation. He endeavors to calculate the quantity of evaporation by the following new formula:

$$21)\quad u=A\Sigma(t-t')w$$

where A is a constant, Σ is the sign of summation, t and t' the two psychrometric temperatures, or dry-bulb and wet-bulb, w the velocity of the wind. This is identical with the second part of my formula (5) above given; but this single expression can not be correct since it indicates that there would be no evaporation when $w=0$.

De Heen (**11**) publishes the results of observations on the evaporation when a current of gas flows over a liquid and finds the following equation for the rate of evaporation:

$$22) \quad u = AF(100 - 0.88f)\sqrt{V}$$

where F is the vapor pressure for saturation at the temperature of the liquid, f is the percentage of the relative humidity of the air before evaporation, V the velocity of the current, A is a constant.

INSTRUMENTS AND OBSERVATIONS.

Instruments.

Several arrangements have been proposed for the purpose of obtaining precise results with the least possible labor. The first observations were made by simply weighing a vessel filled with water at stated times. The successive steps in the development of evaporometers were as follows:

1869. Lamont, at Munich in 1869, described his evaporometer which consisted of two communicating tubes, one of them surmounted by a broad open basin for evaporation, the other having a piston and micrometer for the measurement of the depth evaporated.

1872. Prettner (**12**) employed a vessel in the form of a rain gage; it has a stopcock near the bottom by which the water equivalent of any rain that has fallen into the gage may be drawn off; there is also a fine stream of water at command by which the level of water in the evaporometer may be carefully raised at stated times daily, to the needle point that indicates a constant level.

1873. Piche, in France in 1873, proposed a graduated tube closed at the upper end, filled with water, and having the lower end covered with a small circular piece of bibulous paper from which the moisture evaporates. By reason of the cheapness of this apparatus, it has found many applications, chiefly in France, although its indications are much in excess of the evaporation from an open water surface in a vessel.

1874. F. Osnaghi (**13**), of Vienna, proposed an evaporometer in the form of a balance, with an index which is brought back to the first or standard reading by the addition of water flowing from a graduated tube. This instrument can also be adapted for self-registration.

1875. John Greiner (**14**), of Munich, constructed an apparatus in which a definite quantity of water after evaporation, flows into a graduated vessel for measurement and is then thrown away.

1875. The only method practicable throughout both summer and winter is that of weighing, and, in 1875, Wild, of St. Petersburg, provided 20 stations in Russia with instruments of his own invention consisting of a balance whose lever carries on one side the evaporating vessel while the other side is provided with a weight to counterbalance the vessel, and ends in an index showing, on a graduated scale, the quantity of moisture evaporated.

Analogous methods of observation have been used in Austria for 20 years under the direction of Hann.

Observations.

As already mentioned, the observations by Dalton in England, and Schübler in Germany, are the oldest. Then come the publications of Maurice at Geneva, 1796–97, who measured the evaporation from water and earth. By the same method Gasparin observed at Orange, France, in 1821–22. The annual evaporation and rainfall as found by these observers were:

Station.	Annual evaporation.		Annual rainfall.
	From water.	From earth.	
	Mm.	*Mm.*	*Mm.*
Geneva, 1796.....	1,210	402	654
Orange, 1821–22..	2,281	579	722

Schübler, at Tubingen, obtained 647 mm. as the annual evaporation in the shade. Stark, at Augsburg, from a series of 14 years' duration obtained 1627 mm. as the annual evaporation in the full sunshine. Schübler also investigated the influence of the wind, and found on the average an evaporation in windy weather double that in calm weather. The maximum rate of evaporation occurred with northwest winds in summer and southwest in winter; the minimum rate, with southwest winds in summer and southeast in winter. In 1826 Schübler found that a thickly grown field of grass during July and August evaporated twice as much as a surface of open water, both grass and water being in the shade. Since 1840, observations on evaporation have been made at Madeira and in the Azores; the annual amounts are: At Delgada, 765 mm.; St. Miguel, 1,050 mm;. Funchal, 2,027 mm.

In 1855 Prof. Chapman, of Toronto, Canada, compared the evaporation of salt sea water with that of fresh lake water and found that the former was 54 per cent of the latter. In July, 1867, Prof. Ragona, of Modena, Italy, obtained nearly the same results, but found the percentage to vary with the temperature and moisture of the air.

According to Hartig forest areas evaporate less than an equivalent surface of water or of naked earth. Schübler found during the season of vegetation that the daily evaporation from one square foot of water surface was about 1 cubic inch, corresponding to an average depth of about 1 line, or one-twelfth of an inch; for naked earth he found 0.60 line and for forest 0.25 line. Lawes states that a wheat plant evaporates in one day ten times its own weight of water; in dry weather the leaves are slack and the evaporation diminishes (**15**).

Dufour (**16**), of Lausanne, published the results obtained since 1865 with his apparatus, which he calls the *siccimeter* and which is exposed to full sunshine. He found the annual average evaporation for the interval 1865–1870 to be 756 mm. and the average rainfall 924 mm.

Pfaff (**17**) in 1870 published his investigations on the influence of trees on the moisture of the air and the ground. Observations were made four times a day from May 18 to October 24. The evaporation from the branches was two or three times greater by day than by night; from fresh branches three and one-third times greater in the sunshine than in the shade. Unger had found the same result. The comparison with evaporation from an open water surface showed the latter to be from 1 to 13 times greater than the evaporation from an equal surface of leaves. The loss of water from a tree by evaporation is eight and one-third times the amount of rainfall on an area equal to that covered by the crown of the tree.

1873. Ebermayer, of Munich, in 1873 published the results of observations made in Bavaria on the influence of the forest on moisture and evaporation. The mean of the years 1868–1870 shows that the evaporation from the forest as compared with the evaporation in the open field is 35 per cent in summer, 40 in the autumn, 47 in the winter, and 45 per cent in the spring. In the forest the evaporation from the naked ground saturated to a depth of one-half a foot, is a little more than that from an equal surface of water. The minimum ratio of the evaporation in the forest to that in the open field is 26 per cent in October and the maximum is 56 per cent in April. A cover of litter lessens the evaporation by 40 or 50 per cent in the forest and by 22 per cent in the open field. The evaporation from overgrown ground covered with litter is 85 per cent of that from the same surface free from litter.

1874. Marié-Davy, of Paris (Annuaire de Montsouris, 1873), gives a review of the observations hitherto made relating to the evaporation from the ground and its relation to the rainfall. The first observations are those of Maurice and Gasparin already mentioned. Then came the results obtained by E. Risler (**18**) in 1867–1869, at Calèves, Vaud, Switzerland, who prepared a field of 12.3 hectares for measurements of the rainfall and of the water drained from the ground. He found that on the average the rainfall was 971 mm. and that 256 mm. of the water flowed off, leaving a difference of 715 mm. to represent the evaporation. But if the field was well cultivated, in the summer time nothing ran off for a rainfall of from 30 to 100 mm. a month. In 1869, Risler also measured the quantity of water at various depths in the soil; on August 24–26, during very dry weather, and on September 10 and 11, after a considerable rainfall. In the springtime on digging into the ground he found that the water penetrated to a depth of 0.31 m. in broken soil; but only 0.29 m. in meadows, 0.14 m. in turf, 0.04 m. in a forest of small oaks, and 0.03 m. in a forest of tall oaks.

1869. At Montsouris near Paris, in 1869, July 20–28, Marié-Davy observed the evaporation of plants with the following results: From a field of turf, 33.4 mm.; from a field of beans, 25.7 mm.; of juniper, 16.8 mm.; and of thuja 12.8 mm. He found the evaporation from branches of trees to be as follows: Red beech, 8.2 per cent of the evaporation from open water; poplar and linden, 5.1 per cent; oak, 4.5 per cent; elm, 3.4 per cent. Similar experiments were made by Risler in 1870–71. He calculated the evaporation from the leaves contained in a vertical cylinder extending from the top of the foliage down to a base of 1 square meter of the surface of the ground and found the following daily averages in millimeters: Lucerne (medicago), 3.4 to 7.0; meadows, 3.1 to 7.3; wheat, 2.7 to 2.8; corn (maize), 2.3; fir trees 0.5 to 1.1; oak trees, 0.45 to 0.8.

1871. H. C. Russell, Sydney, New South Wales, has made and regularly published observations since 1871.

1879. Von Höhnel (**19**), of Vienna, in the "Mittheilungen a. d. forstlichen Versuchswesen Oesterreichs," Bd. II, pp. 47–90 (Abstract in Wollny Forsch., 1881, IV, pp. 435–445), published an interesting treatise "On the Transpiration of Forest Trees compared with the Meteorological Relations of the Forest." He mentions the earlier researches, esteeming those by Wollny of Munich as the best. These were made on plants with roots growing in zinc pots. He himself operated on whole trees five or six years old and from 50 to 80 centimeters high, growing in pots, taking all the necessary precautions. Von Höhnel found greatly varying amounts of water lost through the leaves. His experiments made from June to November 30, 1878, on 20 different species gave as the minimum loss 3,207 grams of water per 100 grams weight of dry leaves of the black fir; the maximum was 67,987 grams of water lost by 100 grams weight of the dry leaves of the birch. The rainfall on the ground area covered by the trees was found to be more than sufficient for restoring the water lost by transpiration. Wollny has shown that in the summer time nearly all of the rain water can be used up by the plants. One hectare of land covered with beech trees, averaging 115 years old, evaporates during the growing period from 3.6 to 5.4 millions of kilograms; a single beech tree on an average for the whole season evaporates 50 kilograms per day; but in the summer time the daily average is 75 kilograms. For smaller trees from 50 to 60 years old the corresponding amounts are 2.33 million kilograms per hectare per season, and 10 and 15 kilograms per tree daily during the season and during the summer, respectively. For trees from 30 to 40 years old the amounts are 0.68 million kilograms per hectare during the season and 1.0 and 1.4 kilograms per tree daily during the season and during the summer, respectively. The amount of rainfall during the same season of vegetation, June to November, 1878, was at least 3,000,000 kilograms per hectare and for the whole year 7,000,000 kilograms. The water lost by transpiration in a summer's day from 1 hectare of beeches is 45,000 kilograms for the trees 115 years of age; 20,000 for trees 50 or 60 years of age; and 5,000 for trees 30 or 40 years of age.

1880. E. Stelling (**20**), of St. Petersburg, publishes the annual variation of evaporation at 20 Russian stations since 1875. The variations depending on geographical position are exceedingly large; the total annual evaporation varies from 251 mm. at Novo-Alexandria to 2,321 mm. at Petro-Alexandrovsk.

1882. Prof. Th. Langer (**21**) from observations with four Piche evaporometers at Mödling, near Vienna, finds the following relative results: Calling the amount evaporated in the sunshine and ordinary air 100; in the sunshine but near a great basin of water it was 98.3; in an instrument shelter (von Lorenz pattern), 98.3; in the ordinary wooden shelter of the meteorological station at Mödling, 62.

1884. Carl Eser (**22**) publishes the results of observations on the influence of the physical and chemical properties of the soil on its evaporating power. His work was done in the laboratory and experiment field at Munich, and he states several general connections between evaporation, the moisture of the ground, the depth from which evaporation comes, the nature of the surface, the organic and inorganic contents of the soil, the fineness and coarseness of the soil, its color, its covering of living plants or of dead and dry material, its inclination to the sun's rays, etc. The laws deduced by him are of great interest but are so numerous that I have not the space to communicate all of them. In the saturated state all kinds of soil evaporate nearly the same amount. The loss of water at the surface is restored from below by capillarity as long as the water stored up in the soil exceeds 50 per cent of its maximum capacity. After this superficial layer has been greatly dried the influence of insolation, wind, etc., in producing further evaporation is appreciably diminished. Garden mold evaporates the most water; sand evaporates least. A cover of living plants evaporates the greatest quantity of water; one of of dry materials the least. Adding salts to the soil in the usual quantities for fertilizing purposes has no appreciable effect on the evaporation.

1881. J. B. Lawes, J. H. Gilbert, and R. Warington (**23**) in their treatise on the amount and composition of the rain water and drainage water at Rothamsted communicate investigations made by means of the lysimeter, using vessels the surfaces of which were each 0.001 of an acre, and which were filled with soil in its natural state. For the period 1870–1880 they found the following average results:

Rothamsted evaporation results, 1870–1880.

Season.	Rainfall.	Drainage water.	Evaporation.
	Inches.	*Inches.*	*Inches.*
April–September	16.36	4.39	11.97
October–March	14.67	9.10	5.58
Total, year	31.03	13.49	17.55

1887. John Murray (**24**) gives the calculated total annual rainfall on the land surface of the globe, based on the rain maps of Loomis and a comparison of the "runoff" and the evaporation at different latitudes, from 60° N. to 40° S. For the total land surface of the globe the annual rainfall amounts to 111,800 cubic kilometers; the water running off is 24,600 and the water evaporated is 87,200 cubic kilometers.

1886. Dom. Ragona (**25**) gives the relative evaporation in sunshine and shade at two stations having different positions and altitudes. At both stations the maximum ratio follows the minimum of actual evaporation at an interval of 16 days, and the minimum ratio follows the maximum evaporation at the same interval of time.

1890. Ang. Batelli (**26**), of Riva, near Turin, has made comparative measurements of the evaporation from open water and saturated soil in sunshine and in shade. He finds that more water is evaporated during the period of rising temperature, from the moist soil than from the surface of water; but with falling temperature less is evaporated from the ground than from the water. During an increasing velocity of the wind the evaporation from open water increases more rapidly than from the moist ground. An increase in the humidity of the air favors evaporation from the ground more than evaporation from water.

1890. Prof. Alexander Wocikoff (**27**) replies to a criticism on his work on the evaporation from and the condensation on snow and ice surfaces, and states that the observations of Weyprecht show that in winter time the evaporation is greater than the condensation and that in general this is true whenever the dew point is lower than the melting point of ice. Dr. P. A. Müller (**28**) of St. Petersburg confirms Woeikoff's statement by means of observations, made at the request of Abels, at Catherinenburg from December 21, 1890, to February 28, 1891, which showed that evaporation took place during 73 per cent of the hours of observation, but condensation during only 23 per cent.

1889. Symons (**29**) enumerates several evaporometers and quotes the results obtained by their use. Among these Col. Rogers Field, observing at Strathfield Turgiss from 1870 to 1883, with a water basin of 689 square feet area and 2 feet deep, found the mean annual evaporation to be 448 mm.; the minimum was 347 mm. in 1879 and the maximum 599 mm. in 1870. The same vessel exposed in London by Symons gave 90 mm. less than at Strathfield.

1892. Prof. Franklin H. King (**30**) published his "Observations and Experiments on the Fluctuations in the Level and Rate of Movement of Ground Water on the Wisconsin Agricultural Experiment Farm and at Whitewater, Wis." The observations were begun in 1888 with the design of investigating how far the daily periodic evaporation from naked ground or soil covered with vegetation could influence the quantity of water stored up in the soil beneath. A field of 11 hectares was at his disposition, which was at first provided with 24 wells connected with a system of drainage pipes; then 21 more were added, in digging which due regard was had to the variations in the topography of the land, distance to standing water, character of the soil, and the kinds of vegetation. After 1891 self-registering instruments of his own invention were employed. There was found to be a variation in the height of the level of the ground water in inverse ratio to the changes of atmospheric pressure, but in the same direction as the changes in temperature; in the neighborhood of cultivated ground the level of the ground water was depressed more than near naked ground.

In these few lines I have attemped to mention the most important researches on evaporation, both theoretical and practical. For want of space it was impossible to enumerate the results of the regular observations now being made in Russia, Austria-Hungary, Germany, France, Italy, England, and the United States, which are regularly published, as well as those at Manila and the Azores. I hope that nothing important has been omitted.

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REPORT OF THE METEOROLOGICAL STATION AT BERKELEY, CAL., FOR THE YEAR ENDING JUNE 30, 1913.[1]

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[Dated University of California, Berkeley, Cal., Apr. 7, 1914.]

The University of California has carried on meteorological work at Berkeley (lat. 37° 52′ N., long. 122° 16′ W. Gr.; H, 98 meters; h_t, 1.5 meters; h_r, 4.6 meters) since October 16, 1886, in cooperation with the United States Signal Service and its successor, the Weather Bureau. This work was a part of the activities of the Students' Observatory until July 1, 1912, when it passed to the Department of Geography. This report is the first of a series of annual reports to be issued by the university.

During the fiscal year ending June 30, 1913, the following observations were made at 8 a. m. and 8 p. m. Pacific time:

1. Temperature of the air (dry-bulb thermometer).
2. Temperature of evaporation (wet-bulb thermometer).
3. Maximum temperature in the preceding 12 hours.
4. Minimum temperature in the preceding 12 hours.
5. Pressure of the air.
6. Amount of cloud, and weather.
7. Wind direction and estimated velocity.
8. Precipitation in the preceding 12 hours.

In addition to the observations at the regular hours, a record has been kept of the general character and prevailing wind direction of each day, the times of beginning and ending of precipitation, of the occurrence and character of fog, and of the occurrence of frost; an attempt has been made to record occasional meteorological phenomena of interest. The recording instruments have furnished continuous records of air temperature, air pressure, and relative humidity; these automatic records are complete from the times of the installation of the instruments and are correct except for such errors as are inherent in the instruments and which are not large.

The results of the observations have been recorded as made upon blank forms of the United States Weather Bureau. In addition to the figures obtained by observation, the following have been computed for each observation: Air pressure, corrected for temperature and local gravity; air pressure at sea level; dew point; relative humidity; and pressure of aqueous vapor. The range of temperature and the mean temperature for each day, the change from the mean of the preceding day, and the total precipitation for each day have been computed.

The instruments were exposed on the campus of the University at Berkeley, 19 kilometers (12 miles) east-northeast from the Golden Gate and the Pacific Ocean. The slope from the campus to San Francisco Bay is gentle, about 90 meters, 300 feet, in 3 kilometers, 2 miles. To the east the Berkeley Hills rise abruptly to elevations of over 300 meters, 1,000 feet, above sea level. The thermometer shelter and the rain gage are located at the Students' Observatory, on the west side of a small hill. This location probably provides good air drainage, with the result that temperatures at the location of the thermometers are probably higher than those at the bottom of the valley a few hundred meters away.

A summary of the meteorological conditions at Berkeley for the year will be found in Table 1 [omitted].

It was deemed advisable to use the C. G. S. system of absolute units as this report begins a new series and no previous reports have determined the style so that rational units may be used without complication. For this reason the question was decided wholly on the basis of the proper units.

Owing to a change in the thermometer exposure the temperatures for the year are not strictly comparable with those of preceding years. In general the temperatures under the freer new exposure show higher maxima and lower minima than under the former conditions.

Table 1 [omitted] shows the weather conditions for each month of the year. Days with less than three-tenths of the sky was cloud covered through the day, or on which the sky cloud covered for less than three-tenths of the time, were recorded as clear. Days with more than seven-tenths of the sky covered through the day, or cloudy more than seven-tenths of the time, were recorded as cloudy. All other days were recorded as partly cloudy. The partly cloudy days fall into two classes, those on which the sky was more than three but less than seven-tenths cloudy throughout the day, and those on which the sky was overcast or nearly so for a part of the day and clear for a part of the day; in either case the average amount of cloud for the day was between three-tenths and seven-tenths. The type of day on which the sky was partly cloudy throughout the day is more usual in the winter than in the summer months; it is generally associated with the margin of a cyclone, and may occur at the beginning or toward the end of a passage with the center near the station, or during the passage of a cyclone with the center at some distance from the station. The other type of partly cloudy day is probably the more common at Berkeley. In summer this type occurs with fog or "high fog" in the morning or evening hours, or both, while the greater part of the daytime hours are clear. In winter there is a similar condition when "tule fogs" have drifted southward from the marshes of Suisun Bay and the Sacramento River. The two types of partly cloudy day are the cyclonic, which is the first-mentioned, and the noncyclonic of the summer and the anticyclonic of the winter, which together constitute the second type mentioned.

The monthly extreme temperatures since the opening of the station are given in Table 2.

[1] *Abstract of* University of California Publications in Geography, v. 1 (No. 6), pp. 247-306, issued Apr. 7, 1914.